

# **VeHICaL: Verified Human Interfaces, Control, and Learning for Semi-Autonomous Systems**

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<http://vehical.org>



THE UNIVERSITY  
of NORTH CAROLINA  
at CHAPEL HILL

NSF CPS PI Meeting  
October 31, 2016

# Human Cyber-Physical Systems (h-CPS)

CPS that operate in concert with humans



Driver Assistance in Cars



Fly-by-wire Cockpit Interfaces



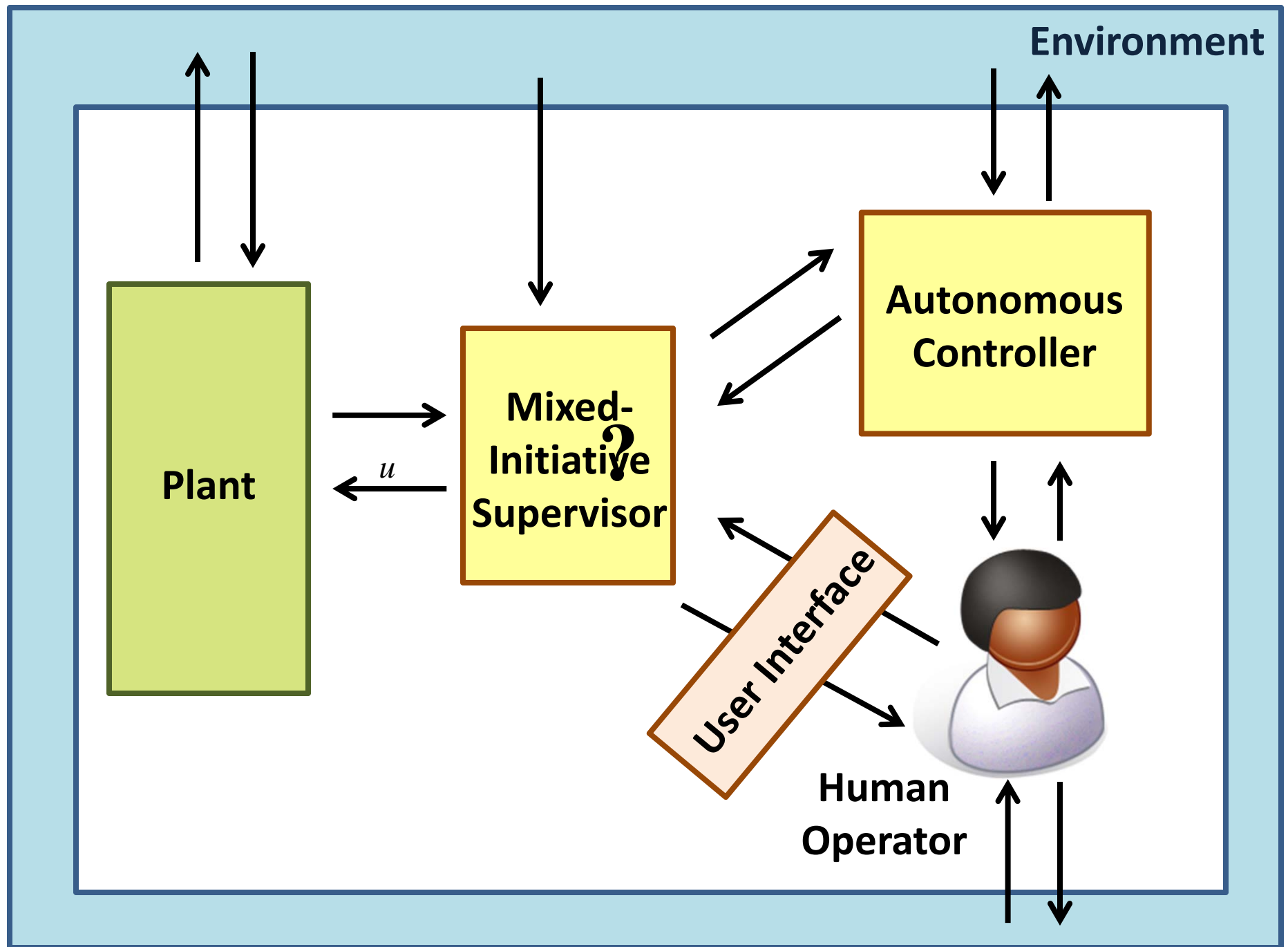
UAVs with Human Operators



Robotic Surgery &  
Medicine



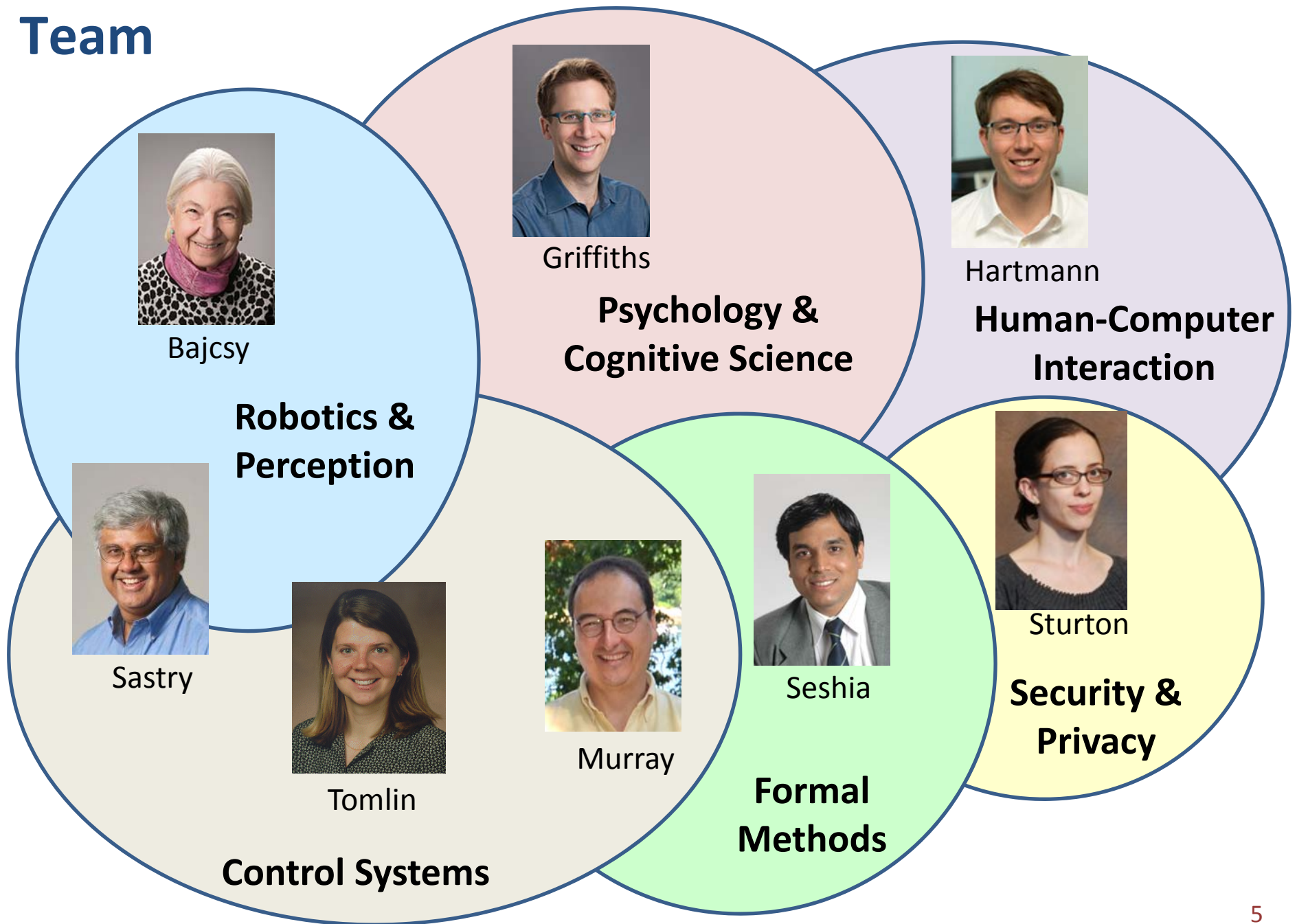
Semi-Autonomous Manufacturing



# Overall Project Objective of VeHICaL

*To develop a **science of verified co-design** of **controllers** for semi-autonomous cyber-physical systems and **interfaces** between **humans** and cyber-physical components*

# Team



# Motivating Applications

- **Semi-Autonomous Automobiles**

TECHNOLOGY

The New York Times

## *The 15-Point Federal Checklist for Self-Driving Cars*

By CECILIA KANG SEPT. 20, 2016

## *A Lesson of Tesla Crashes? Computer Vision Can't Do It All Yet*



- **Semi-Autonomous UAVs**

## FAA Expects 600,000 Commercial Drones In The Air Within A Year

August 29, 2016 · 3:10 PM ET



AARIAN MARSHALL TRANSPORTATION 08.30.16 1:28 PM

## HOW TO ACE THE FAA'S NEW TEST AND BECOME A PRO DRONE PILOT

WIRED



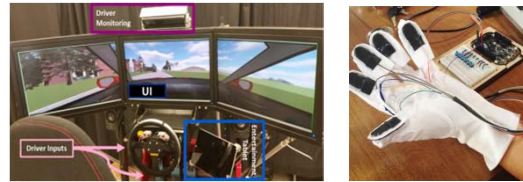


# Project Goal: Develop Science of Design of h-CPS with Provable Guarantees on Behavior

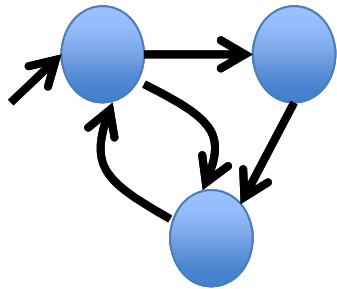
## Some Major Unsolved Problems to be Tackled:

- **Effective Sharing of Control** between Human and Autonomous Controller
- **Modeling Human** Cognition, Perception, and Action, and developing **Sensing Strategies** to infer and evaluate such models
- **Uncertainty in h-CPS Dynamics *and* in Modeling**: need new techniques blending Verification, Learning, and Control
- **Verifiable Human-Computer Interface** Design *integrated with* Control System Design
- **Privacy-preserving Learning** of Models of h-CPS

## Sensing & HMI Design



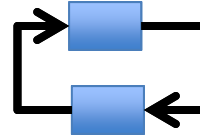
## Formal Modeling & Specification



## Verification



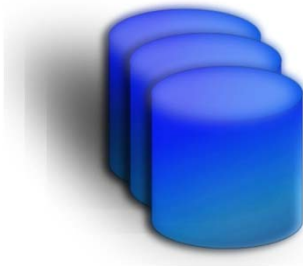
## Control



## Security & Privacy



## Learning Models from Data

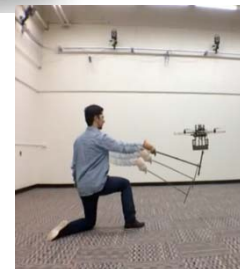
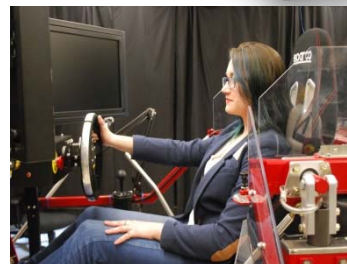


**VeHiCal**

## System-level Integration & Validation



## Evaluation & User Studies





# Four Project Thrusts

1. Specification and Modeling
2. Learning, Verification, and Control
3. Human-Machine Interface Design & Verification
4. Testbed and Evaluation

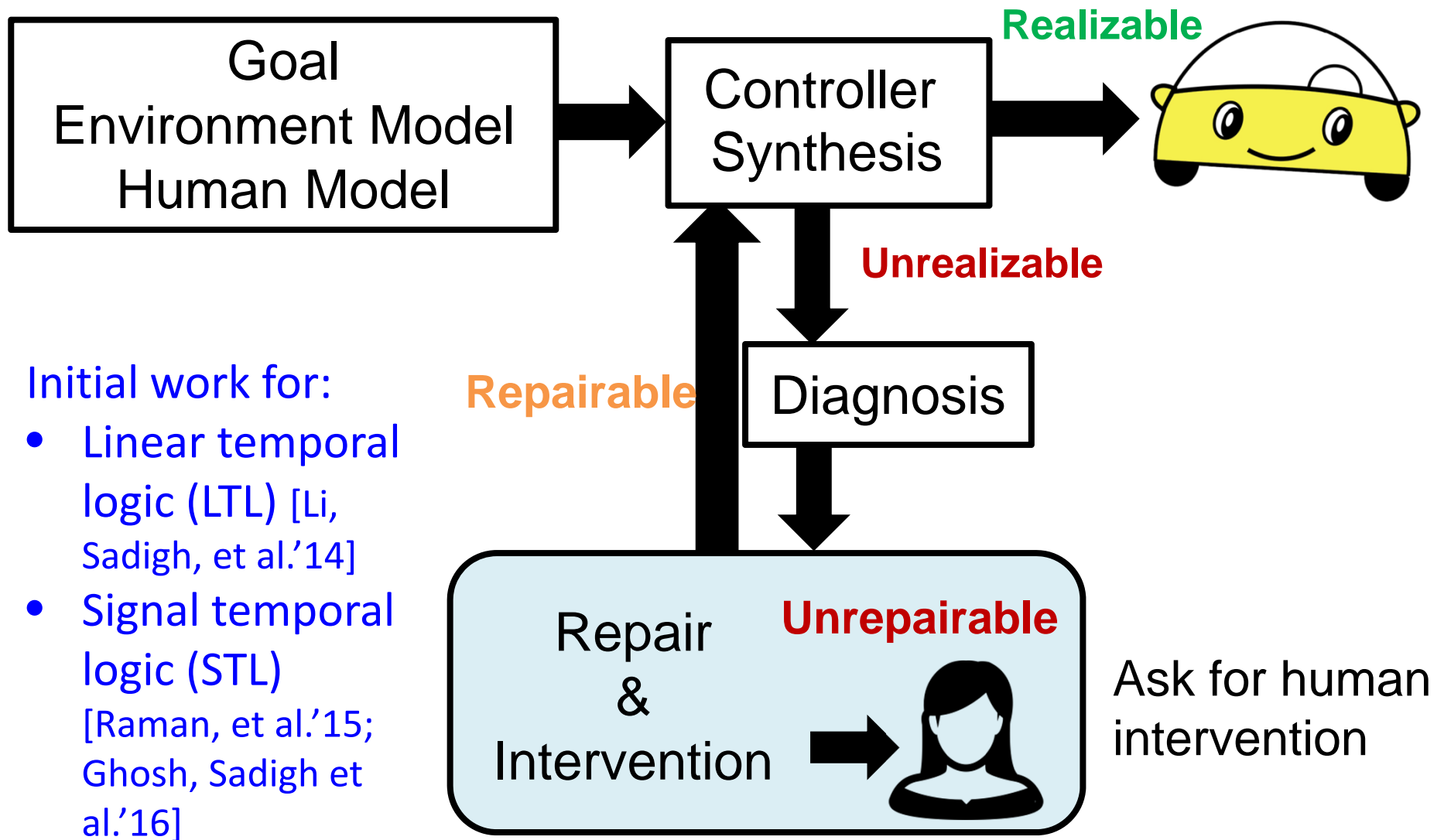
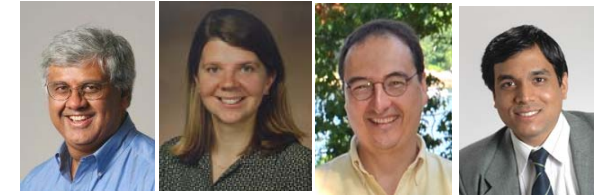
# Specification for h-CPS: What does “correctness” mean?

[Li, Sadigh, Sastry, Seshia, TACAS'14]



- Safe & Correct Autonomy
  - Autonomous mode should be proved correct
- Effective Monitoring
  - Must monitor all relevant environment variables
- Prescient Switching
  - Sufficient lead time to switch between human & auto
- Minimally Intervening
  - Should *rarely* request human intervention
- Other Properties:
  - Security & Privacy
  - HMI Properties: Absence of Mode Confusion, ...

# Correct-by-Construction (Semi-Autonomous) Control



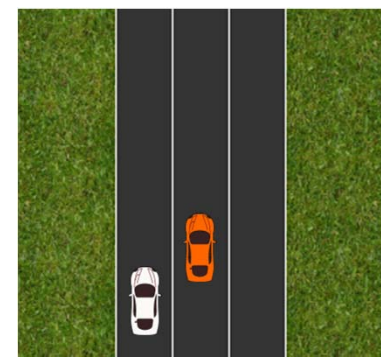
# Human-Aware Control of Vehicles

[Sadigh, Sastry, Seshia, Dragan; RSS, IROS '16]

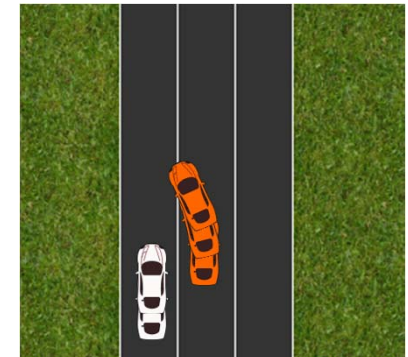


Leverage human *responses* to estimate human internal state.

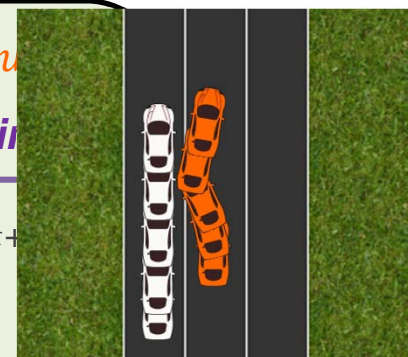
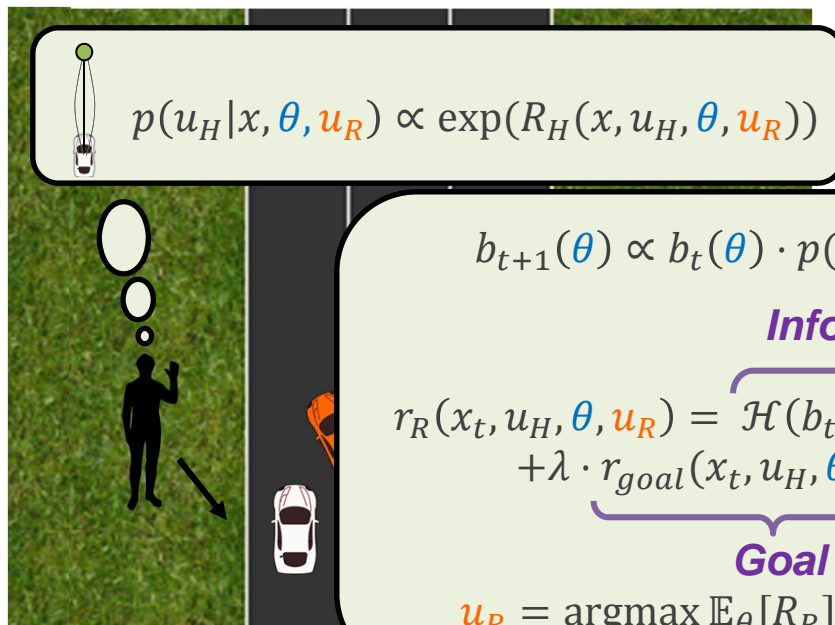
## SAMPLE RESULT



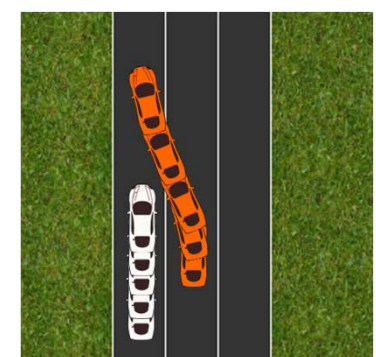
Lane Change



Nudging In



Distracted Human



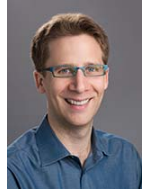
Attentive Human

# Human Modeling: Data-Driven Modeling and the “Bounded Optimal” Model



- Uncertainty in human behavior and variation (person to person) are central aspects of h-CPS
  - Probabilistic formalisms, learned from data
  - Consistent with formalisms using in verification and control
- Model human behavior based on “Resource Rationality” [Griffiths, Lieder, & Goodman, 2015]
  - Trade off error with the cost of computation, assuming an abstract computational architecture
  - an instance of “bounded optimality”: choosing the best algorithm to solve a problem (Russell, 1995)

# Resource rationality in VeHICal: Directions



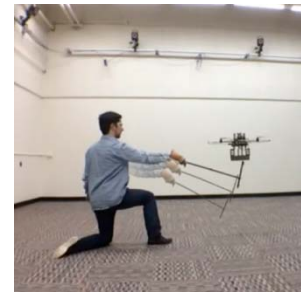
- **Prediction:** Modeling the allocation of cognitive resources in dynamic environments
  - e.g., do we make rational choices about when to check our texts when driving?
- **Inference:** Developing models that can be used to infer when/how humans are resource-limited
  - e.g., behavior patterns that result from having less resources for tracking, relevant to prescient switching



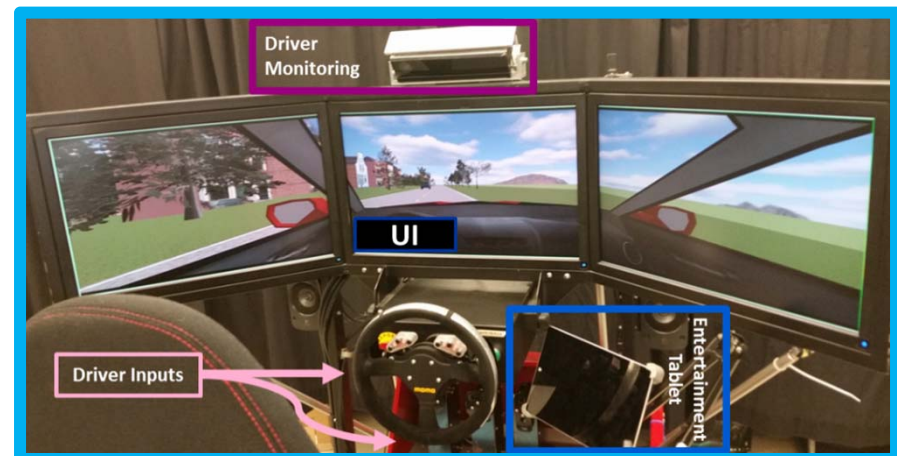
# Experimentation on CPS Testbeds



- **Driving Simulator Testbed:** Force Dynamics 401CR (industrial simulator with motion feedback)
- **Automotive:** Partnerships with automotive companies
- **UAVs:** Tomlin lab, partnerships with drone companies
- **Jacobs Hall:** State-of-the-art labs for rapid prototyping of interfaces and hardware

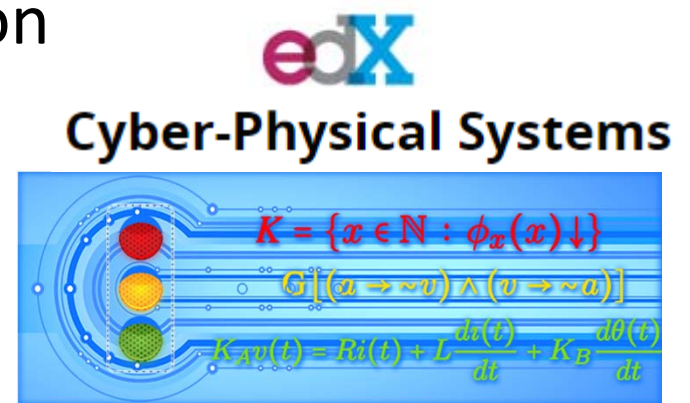


**Initial work** [Rezvani et al., ITSC'16]:  
Impact of user interface  
design on transfer of control



# Education and Outreach activities

- Joint development and dissemination of educational materials on h-CPS
  - *Online course on h-CPS* jointly offered by PIs
- Joint mentoring of postdoctoral researchers
- Summer programs for undergraduate and high/middle school students
  - Projects conceived of jointly and offered in a coordinated manner to amplify the overall impact



## **VeHiCaL: Verified Human Interfaces, Control, and Learning for Semi-Autonomous Systems**

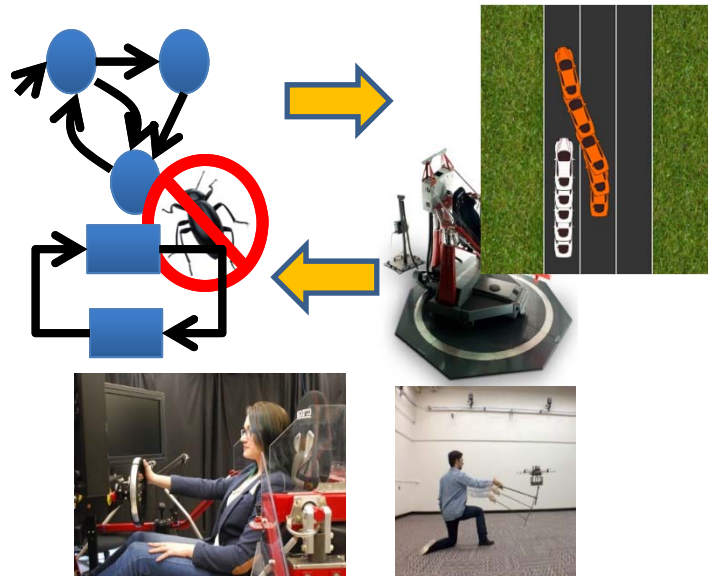
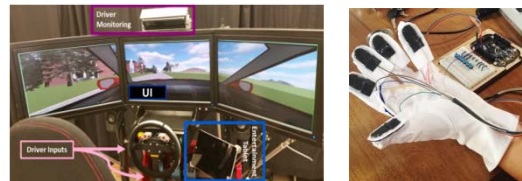
### **Challenge:**

- *Co-design human interfaces and control for human-cyber-physical systems with **provable guarantees***
- Apply to semi-autonomous vehicles (ground and air)

### **Solution:**

- Integrate Learning, Verification and Control
- Bounded Resource Rational Human Modeling
- Prototype Controllers & Interfaces, Evaluate on Testbed

**VeHiCaL**



### **Scientific Impact:**

- Developing a Science of Co-Design of Human Interfaces and Control
- Bridging Model-Based and Data-Driven Design of CPS

### **Broader Impact:**

- Significantly improve safety, security, and performance of systems where humans interact closely with automation
- Involve middle/high-school and undergraduate students in VeHiCaL activities

CPS Awards 1545126, 1544714, 1544924

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